APPLICATION

FOR

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TITLE: **PREDICTING PERFORMANCE OF TELEPHONE LINES FOR DATA SERVICES**

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PREDICTING PERFORMANCE OF TELEPHONE LINES FOR DATA SERVICES

Background of the Invention

This application relates generally to communications networks, and more particularly, to predicting the performance of telephone lines when transmitting data.

Public switched telephone networks, i.e., plain old telephone systems (POTS), were originally designed for voice communications having a limited frequency range. Today, the same POTS lines often carry data transmissions. Since data transmissions generally have different frequency properties, a POTS line that works well for transmitting voice may work poorly for transmitting data. Since POTS lines may not work well for data transmissions, both telephone operating companies (TELCO's) and customers want tests for predicting which lines can transmit data.

In the past, telephone operating companies (TELCO's) performed pre-qualification and pre-disqualification tests on POTS lines prior to connecting data transmitters to them. These tests identified some situations where the line can or cannot support data transmissions without remedial actions. But, the pre-qualification and pre-disqualification tests both produced a significant number of mispredictions, i.e., false positives and false negatives.

More critically, current pre-qualification tests for POTS lines are frequently not automated and consequently labor intensive. Often, they demand skilled interpretations of high frequency parameters of a line to determine its data transmission capabilities at high speeds. The tests do not make full use of automated testing systems, e.g., as described in U.S. patent 5,699,402, which is herein incorporated by reference in its entirety. At a network scale, such tests would be very expensive to implement.

Furthermore, as data transmission demands increase, simple pre-qualification or pre-disqualification is no longer sufficient. Now, customers also want information enabling them to choose between competing options for transmitting data. Instead of simple qualification or disqualification, the customer frequently wants to know which transmission medium and/or devices will work better. Simple pre-qualification does not provide customers with a way to compare the different viable options for transmitting data.

The present invention is directed to overcoming or, at least, reducing the affects of one or more of the problems set forth above.

Summary of the Invention

In a first aspect, the invention provides a method of predicting the performance of a customer line for data transmission. The method includes measuring electrical properties of the customer line from a central location, identifying a line model from the measurements, and identifying a modem model for a modem selected for use with the customer line. The modem model gives performance data for the selected modem. The method also predicts performance data for the customer line when operated with the selected modem by combining the line and modem models.

In a second aspect, the invention provides a method of speed qualifying a customer line for data transmission. The method includes identifying a proxy line, performing one-ended electrical measurements on the proxy line, and predicting a data rate for the customer line from the measurements. The customer line is unconnected to a central switch from which the

one-ended measurements are performed. The proxy line is connected to the switch and is also located in the same cable carrying the customer line.

In a third aspect, the invention provides a system for speed qualifying customer lines for data transmission. The system includes a computer, a telephony switch coupled to a portion of the lines, and a measurement unit coupled to both the switch and the computer. The switch is adapted to connect the portion of the lines to a network, to perform one-ended electrical measurements on the portion, and to transmit the measurements to the computer. The measurement unit orders the measurements on a selected line in response to receiving a command from the computer. The computer predicts a data rate for the selected line from the results of the measurements.

In a fourth aspect, the invention provides a method of marketing telephone lines to customers. The method includes speed pre-qualifying a plurality of the lines using one-ended electrical measurements performed from a central location. The method sets billing rates for, at least, a portion of the lines at prices that depend on the speed qualification thereof.

In a fifth aspect, the invention provides a method of marketing telephone lines to customers. The method includes speed qualifying each customer line using one-ended electrical measurements and offering high-speed service to a portion of the customers in response to the portion having lines qualified to support high-speed service. The speed qualification classifies each line for either high-speed service or low speed service.

In a sixth aspect, the invention provides a method of marketing telephone lines to customers. The method includes using one-ended electrical measurements to speed pre-qualify each line for either high-speed service or low speed service. The method also includes selectively connecting at least a portion of the lines qualified for high-speed service to particular customers in response to receiving a request for high-speed service from the particular customers.

Brief Description of the Drawings

Other objects, features, and advantages of the invention will be apparent from the following description taken together with the drawings in which:

FIG. 1 illustrates a system to speed qualify customer telephone lines for data transmission;

FIG. 2 illustrates a test apparatus for performing one-ended admittance measurements on twisted-pair telephone lines;

FIG. 3 graphically represents the frequency dependent attenuation both for an average twisted wire pair located in a standard telephony cable and for a particular customer line;

FIGs. 4A-4D are flow charts illustrating a method of finding the attenuation of a line from the attenuation for an average line of FIG. 3 and one-ended measurements;

FIG. 5 is a flow chart illustrating a method for speed qualifying a customer line for data transmission;

FIG. 6 is a flow chart illustrating a method for predicting the data rate of a line in the method of FIG. 5;

FIG. 7 is a flow chart illustrating a method for predicting the data rate from line and modem models;

FIG. 8 is a graphical representation of the method of FIG. 6 for a modem model in which the data rate depends on the line's normalized noise level and average normalized line length;

FIG. 9 is a flow chart illustrating a method of finding a line model from one-ended measurements;

FIG. 10 is a flow chart illustrating the use of data mining to derive rules relating the line attenuation to one-ended measurements; and

FIG. 11 is a flow chart illustrating a method of marketing telephone lines for data transmission.

Description of the Preferred Embodiments

This application incorporates U.S Serial No. 60/106,845, filed November 3, 1998, by Roger Faulkner et al, by reference in its entirety.

SPEED QUALIFICATION SYSTEM

FIG. 1 illustrates a portion of a POTS telephone network 10 for speed qualifying customer telephone lines 12-14, 19, 21. The network 10 includes the customer lines 12-14 that connect customer units 16-18, i.e., modems and/or telephones, to a switch 15 located in a TELCO central office 20. Each line 12-14 is a standard twisted two-wire copper line adapted for telephone voice communications. The two wires are generally referred to as the ring "R" and tip "T" wires. The switch 15 may be a POTS switch or any other device for connecting the lines 12-14 to a telephone network, e.g., a digital subscriber loop access multiplexer (DSLAM) (not shown). A very large portion of the length of each customer line 12-14 is housed in

a standard telephone cable 23 that caries a number of the customer lines 12-14 i.e., more than a dozen. The telephone cable 23 is an environment, which changes the electrical and transmission properties of the individual customer lines 12-14.

The standard cable 23 also houses customer lines 19, 21, i.e., standard twisted pair telephony wires, that are not connected either to the switch 15 or to the customer units 16-18. These lines 19, 21 have been fabricated into the cable in anticipation of increased customer demand at future times. Some of the unconnected lines 19, 21 go to customer residences already having a connected POTS line, e.g., the line 19 goes to the customer connected to the line 14. The other unconnected lines 21 are not routed to a particular customer's residence. But, all the lines 12-14, 19, 21, i.e., connected or unconnected, have a very large portion of their length confined to the telephony cable 23, which similarly influences the transmission properties of each line 12-14, 19, 21 therein.

A measurement unit 22 couples to the switch 15 in the central office 20 via a test bus 25. The measurement unit 22 controls one-ended electrical measurements from the central office 20, which are used to obtain admittances and noise levels for the lines 12-14 being measured. To perform a measurement, the measurement unit 22 signals the switch 15 to disconnect a selected line 12-14 from the telephone network and to connect the selected line 12-14 to measurement apparatus (not shown) within the switch 15. Then, the measurement unit 22 signals the apparatus to perform selected measurements. The measurement unit 22 signals the switch 15 to reconnect the line 12-14 to the network after measurements are completed. The bus 25 returns results from the measurements to the measurement

unit 22. Such measurements are described in more detail in U.S. Application Serial No. 60/106,845.

The measurement unit 22 is controlled by the computer 26, which selects the type of measurements to be performed and the lines 12-14 upon which the measurements will be performed. The computer 24 sends control signals to the measurement unit 22 through the line 26 and receives data the measurement results from the measurement unit 22 via the same line 26. An executable software program, encoded on storage medium 28, coordinates the tests by the measuring unit 22 and the processing of test data to predict data rates.

The measurement unit 22 and computer 24 speed qualify and/or disqualify the customer lines 12-14 and associated modems for selected data transmission speeds. To speed qualify, the computer 28 must determine, with a high degree of certainty, that the qualified line and associated modems will support data transmissions at a specified data rate without remedial measures. To speed disqualify, the computer 28 must determine, with a high degree of certainty, that the disqualified line and associated modems will not support data transmissions at the specified data rate without remedial measures.

Various embodiments make speed qualification determinations either before the line is in service or while the line is in service. Before a line is transmitting data, the determinations are speed pre-qualifications or pre-disqualifications. After a line is transmitting data, determinations are referred to as speed path testing.

ONE-ENDED MEASUREMENTS ON CUSTOMER LINE

FIG. 2 illustrates an apparatus 27 for performing one type of one-ended electrical measurement used for speed qualifying and/or speed disqualifying of the lines 12-14 of FIG. 1. The apparatus 27 measures the admittances of the tip and ring wires T, R of the selected customer line under measurement. The tip and ring wires T, R of the line 12-14 being measured couple to driving voltage sources V_1 and V_2, respectively, through known conductances G_t and G_r. The tip T and ring R wires also connect to voltmeters V_t and V_r for reading the voltage between the tip wire T and ground and between the ring wire R and ground, respectively. The readings from the voltmeters V_t and V_r enable the computer 24 to determine effective admittances Y_{tg}, Y_{tr}, Y_{rg} between the tip wire T, ring wire R, and ground for the customer line 12-14 being measured.

To determine the admittances Y_{tg}, Y_{tr}, Y_{rg}, the switch 15 connects the voltage sources V_1 and V_2 and the voltmeters V_T and V_R to the tip and ring wires T, R as shown in FIG. 2. After connecting the apparatus 27, the measurements needed to determine the admittances Y_{tg}, Y_{tr}, Y_{rg} entail three steps. First, the measurement unit 22 grounds the point 29 and applies voltage V_2 while measuring the voltages across the voltmeters V_r and V_t. Next, the measurement unit 22 grounds the point 30 and applies voltage V_1 while measuring the voltages across the voltmeters V_r and V_t. Finally, the unit 22 applies both voltages V_1 and V_2 and measures voltages across the voltmeters V_r and V_t. From these three measurements, the computer 24 determines the admittances Y_{tg}, Y_{tr}, Y_{rg} at various frequencies.

During measurements for the admittances Y_{tg}, Y_{tr}, Y_{rg}, the apparatus 27 may apply complex driving voltages V_1 and V_2 that superimpose several frequencies. For example, the driving voltages V_1, V_2 may take the form: $V(N) = A\Sigma_{i=1-45} \cos(2\Pi\_f_i NT + \varphi_i)$. The frequencies f_i, sampling cycle values N (at 152.6 Hz), and phases φ_i are shown in Appendix 1. The computer 24 Fourier transforms both the driving and measured voltages V_1, V_2, V_t, V_r to separate frequency components. From the Fourier transform, the computer 24 finds the real and imaginary parts of the admittances Y_{tg}, Y_{tr}, Y_{rg} by well-known circuit-analysis techniques.

From the admittances Y_{tg}, Y_{tr}, Y_{rg}, several derived properties of the lines 12-14 may be determined. First, a line length can be derived from the capacitances C_{tg} and C_{rg} of the tip wire T to ground and of the ring wire R to ground. For standard bundled telephony cables with twisted tip and ring wire T, R pairs, both capacitances are about 17.47×10^{-9} Farads per 1,000 feet regardless of the gauge. Thus, the one-ended measurement of capacitances gives a measure of the apparent length of the measured line 12-14. Second, the existence of a bridged tap in one of the lines 12-14 can be derived from the existence of an above-threshold peak in the ratio:

$$\mathrm{IM}\left(\frac{\partial^2 Y_{tg}(f)}{\partial f^2}\right) \Big/ \mathrm{RE}\left(\frac{\partial^2 Y_{tg}(f)}{\partial f^2}\right)$$

The presence of a bridged tap substantially effects the capacative measurement of the length of the line. Third, the admittances Y_{tg}, Y_{tr}, Y_{rg} can also be used to predict the gauge mix of the measured lines 12-14. The gauge mix of a line is the ratio of the sum of lengths of the line, which are fat wire, over the full length of the line. Typically, fat wire is

22 and 24 gauge wire, and thin wire is 26 gauge wire. The customer lines 12-14, 19, 21 of FIG. 1 may have segments of fat wire and segments of thin wire. Fourth, a frequency dependent attenuation up to high frequencies can be derived.

A two step procedure is used to derive the high frequency attenuation of the measured lines 12-14. First, the attenuation of the lines is approximated by the frequency (f) dependent average attenuation, **AT**(f). **AT**(f) is the attenuation of an "average" mixed gauge twisted copper line in a standard telephony cable. The average attenuation **AT**(f) is known to approximately be:

$$\mathbf{AT}(x\mathrm{MHz}) = A(x\mathrm{MHz})C_{tg} \text{ with}$$
$$(A(.1\mathrm{MHz}), A(.3\mathrm{MHz}), A(.4\mathrm{MHz}), A(.5\mathrm{MHz}))$$
$$= (.173, .24, .263, .288)\mathrm{DB}/10\text{-}9\mathrm{F}$$

A solid curve 32, shown in FIG. 3, graphically illustrates the equation for **AT**(f) as a function of frequency. Second, for each customer line, the frequency dependent values of the **AT**(f) are adjusted using a method found through data mining. The second step produces the attenuation, **ATT**(f), for each customer line. **ATT**(f) is generally an improved value of the line's attenuation compared to the **AT**(f) for an average line.

Data mining produces a set of logical decision trees, which are used to find **ATT**(f). For each customer line, the computer 24 of FIG. 1 works through the set of logical decision trees. Each decision tree determines whether or not **ATT**(f), at one frequency, is shifted from the value of **AT**(f) at that frequency. At frequencies between those associated with logical decision trees, the computer 24 finds the value of

ATT(f) by performing a smooth interpolation. The dashed line 34 of Fig. 3 shows the **ATT**(f) of one customer line, which was found by the logical decision tree analysis ($M = 10^6$, $K = 10^3$, and DB = decibels).

FIGs. 4A, 4B, 4C, and 4D are flow charts showing the decision trees for finding the values of **ATT**(.1MHz), **ATT**(.3MHz), **ATT**(.4MHz), and **ATT**(.5MHz), respectively. FIG. 3 shows the **ATT**(.1MHz), **ATT**(.3MHz), **ATT**(.4MH), and **ATT**(.5MHz) (triangles) of one customer line, which were found from the **AT**(.1MHz), **AT**(.3MHz), **AT**(.4MH), and **AT**(.5MHz) values (dots). Each decision tree uses logical tests based on lower frequency derived quantities, which are listed in Appendix 2. In Appendix 2, admittances are given in siemens, capacitances are given in Farads, and frequencies are given in Hertz unless otherwise indicated.

The result from each decision tree provides a value of **ATT**(f) at a higher frequency than the frequency used to measure the admittances Y_{tg}, Y_{tr}, and Y_{rg}. Thus, the logical decision trees enable the computer 24 to improve **ATT**(f) for each customer line, at frequencies higher than the frequencies at which measurements are performed on the line.

From a line's attenuation **ATT**(f), the computer 24 can derive a normalized line length (NLL). NLL(f) is the equivalent length of 26 gauge twisted copper telephony line to produce the attenuation **ATT**(f). The value of NLL(f) is approximately:

$$\mathrm{NLL}(f) = \mathbf{ATT}(f)/\{\Sigma^{7}_{j=0}\ P_j\ (\log(f))^{j}\}$$ where the P_j are:

$$(P_0, \ldots, P_7) = 10^3(-1.81718846839515,\ 2.3122218679438,\ -1.25999060284948,\ .38115981179243,\ -.06912909837418,\ .00751651855434,\ -.00045366936261,\ .00001172506721)$$

Averaging NLL(f) over frequencies between 100KHz and 1Mhz provides a averaged normalized line length. The averaged normalized line length and a normalized noise define properties of a line model for the measured customer line 12-14, which allow the prediction of data transmission rates.

The one-ended measurements on the selected customer line 12-14 also include noise power spectra and impulse noise. Noise power spectra are determined directly through one-ended measurements using a spectrum analyzer (not shown) located in the measurement unit 22. Impulse noise measurements employ a differential comparator (not shown) also located in the switch 15. The comparator has an adjustable threshold and produces a digital output pulse for each above-threshold spike on the tip or ring T, R wires. The output digital signal goes to a counter (not shown), which sums the number of counts to produce a rate for above-threshold noise impulses.

Noise measurements may both disqualify and correct predicted data rates of the lines 12-14 being qualified. For high noise levels, synchronization of the line 12-14 for ADSL or ISDN data transmissions becomes impossible, and the noisy line 12-14 must be disqualified. For example, impulse noise rates above about five 150 millivolt-counts-per-second disqualify a line for ADSL transmissions. When noise is not a disqualifier, it still can lower the predicted data rates for the customer line in a manner that generally depends on the modem used with the selected line 12-14.

Referring again to FIG. 1, the customer lines 19, 21 do not connect to the switch 15 and thus, cannot be automatically tested by the measurement unit 22. Thus, speed qualification or disqualification of these lines 19, 21 requires indirect measurements henceforth referred to "proxy measurements".

Proxy measurements are one-ended electrical measurements on a "proxy" line located in the same cable 23 as the unconnected line 19, 21 to be qualified or disqualified. The proxy line connects to the switch 15 and thus, can be tested by one-ended electrical measurements made from the switch 15. For example, the line 14 is a potential proxy line for the line 19 going to the same customer.

The proxy line 14 is located in the same cable 23 as the unconnected lines 19, 21 to be qualified. Thus, both types of lines have undergone the same handling after fabrication of the cable 23. Similarly, if the cable 23 has more than 12 different customer lines, e.g., a standard telephony cable, the various lines 12-14, 19, 21 are in very similar cable environments. Then, electrical measurements on the proxy line 14 can, in some cases, provide a reliable measure of the same electrical properties for the unconnected lines 19, 21. The reliability of proxy measurements may further increase if the proxy line goes to the same residence as the unconnected line, e.g., lines 14 and 19. But, proxy measurements may still be reliable if the proxy line is simply in the same cable 23, e.g., the line 13 as a proxy for the line 19.

LINE PERFORMANCE PREDICTIONS

FIG. 5 is a flow chart illustrating a method 40 of speed qualifying or disqualifying a selected one of the customer lines 12-14 of FIG. 1 for data transmissions. The method has two parts. In a first part, the computer 24 and measurement unit 22 of FIG. 1 rapidly determine whether the selected line 12-14 is pre-disqualified for data transmissions. In the second part, the computer 24 predicts the speed for data transmissions if the selected line 12-14 is not disqualified in the first part.

To determine whether the selected customer line 12-14 is disqualified for transmitting data, the computer 24 or an operator selects the type of data service to be implemented on the selected customer line 12-14 (step 42). Next, the computer 24 determines the qualification requirements for the selected type of data service on the selected line 12-14 (step 44). Next, the computer 24 and measurement unit 22 perform one-ended electrical measurements on the selected customer line (step 46). Then, the computer 24 determines from the one-ended measurements whether the selected customer line 12-14 is disqualified for the selected type of data transmissions (step 48). If the selected customer line 12-14 is disqualified, the computer reports the disqualification status and stops.

The pre-disqualification part of the method 40 is generally more rapid than predicting the actual data rates obtainable. U.S. Patent Application Serial No. 60/106,845, filed November 3, 1998, provides detailed account of some types of measurements and determinations performed in pre-disqualification steps 42, 44, 46, 48. These steps may also include further tests specific to the type of termination at

the customer units 16-18. For example, for ADSL-lite data transmissions the fact that a customer unit 16-18 attenuates high frequencies could be used as a disqualifier test.

If the selected customer line 12-14 is not pre-disqualified at step 48, the computer 24 will predict the data rate of the selected line 12-14 for data transmissions. First, the computer 24 creates a line model for the selected customer line 12-14, e.g., by performing more one-ended measurements on the line 12-14 and deriving the line model therefrom (step 52). At substantially the same time, the computer 24 identifies a modem model to be used with the selected customer line 12-14 (step 54). The modem model may correspond to the modem in the central office 20 and/or the modem at the customer's residence. Next, the computer 24 uses the line model for the selected customer line 12-14 in the modem model to predict the line's performance, e.g., the data rate. Some modem models are a data file stored in the computer 24 and indexed by properties of the line model. Finally, the computer 24 reports the line performance when used with the identified modem (step 58).

FIG. 6 is a flow chart illustrating a method 60 for predicting the performance of the selected customer line 12-14, which was not pre-disqualified for data transmissions at step 48 of FIG. 5. The computer 24 and measurement unit 24 control one-ended electrical measurements carried out by apparatus 27 on the twisted pair T and R of the selected customer line 12-14 (step 62). The measurements determine the three admittances Y_{tg}, Y_{tr}, Y_{rg} of the tip and ring wires T, R and the noise levels in the selected customer line 12-14. Next, the computer derives a number of other properties of the selected customer line 12-14 from the one-ended measurements (step 64). As

discussed above, the derived properties may include a line length, the existence or absence of one or more bridged taps, the gauge mix of the line, impulse noise level, frequency dependent attenuation, normalized line length, and the noise spectrum.

From these derived properties, the computer 24 calculates a second-level derived property—the average normalized line length. The average normalized line length is the length of 26 gauge paired twisted copper wires, located in a telephony cable 23 with at least 12 other twisted wire pairs, which would have substantially the same transmission properties.

The computer 24 also selects a modem, e.g., in response to a customer's request or a TELCO's command to speed qualify or disqualify the line for a particular modem type (step 66). Next, the computer 24 looks up a modem model for the selected modem in a database (step 68). The modem model is a table of performance data, i.e., data transmission rates, indexed by the averaged normalized line length and the line noise level. The computer 24 may leave the modem model in active memory while waiting for data on the line model associated with the selected customer line 12-14. Next, the computer uses the line model data in the modem model to find a predicted data rate for the selected modem in association with the selected customer line 12-14 (step 70). Finally, the computer 24 reports the predicted data rate to the customer or to a readable storage device (step 72).

FIG. 7 is a flow chart illustrating one method for predicting the data rate of the selected customer line 12-14 as shown in step 70 of FIG. 6. The line model is either a set of

rules or a file for the properties characterizing the model. From the line model, the computer 24 reads the average normalized line length (step 82). Similarly, the line model or one-ended measurements determine a normalized noise level associated with the selected customer line 12-14 (step 84). Finally, the computer 24 performs a look up of a predicted data rate in a table defining the modem model (step 86). The modem model's table is indexed by the averaged normalized line length and the normalized noise level. The table is a tabular form representing the modem model for the modem to be used with the selected customer line 12-14.

FIG. 8 graphically illustrates one modem model 90 as a set of curves 92-95 for the predicted data rate. The values from the curves 92-95 depend on, i.e., are indexed by, a line's normalized noise level and averaged normalized line length. The separate curves 92-95 give the predicted data rate for four values of the normalized noise level of the line model. Each curve 92-95 is also dependent on the averaged normalized line length, which is plotted along the horizontal axis.

The predicted data rate can be obtained from the modem model 90 of FIG. 8 by performing a look up with the parameters of the line model. To predict the data rate, the computer 24 looks up one of the curves 92-95 using the normalized noise value from the line model, e.g., normalized noise value 2. Next the computer 24 finds the predicted value of the data rate by looking up the averaged normalized line length, given by the line model, on the horizontal axis, e.g., value 97. The value 101 of curve 93 at the intersection 99 with the value 97 of the averaged normalized line length is the predicted data rate. Of course, the computer does the look ups in a data base indexed

by the normalized noise level and the average normalized line length instead of graphically.

Some modem models also depend on parameters such as impulse noise compensation, noise floor, echo compensation and phase instability compensation. The impulse noise compensation is the ability of the modem to resychronize or to remain synchronized in the presence of impulse noise on the customer line. The noise floor is the noise level below which the modem does not resolve data signals. The echo compensation is the ability of the modem to compensate for reflected signals in the customer line. The phase instability compensation is the ability of the modem to compensate for time-dependent imbalances in the customer line, e.g., time-dependent reflections.

Using the values of each of these parameters, the computer 24 of FIG. 1 adjusts the predicted data rate from the rate predicted by FIG. 8. The modem models attach a figure-of-merit or quality rating to each of the above parameters. For each parameter, the quality rating may, for example, be excellent, good, or bad. The quality ratings determine whether the predicted data rate, e.g., the rate from FIG. 8, is adjusted up, down or not adjusted by the computer 24 to obtain a final predicted data rate. For example, some embodiments adjust the predicted data rate from FIG. 8 up by 10 percent and down by 10 percent for quality ratings of excellent and bad, respectively.

Similarly, some line models include a gauge mix parameter, which is given a quality rating, i.e., high, average, or low. Data mining techniques can be used to infer a test for the gauge mix of a line from the one-ended

electrical measurements. The computer 24 of FIG. 1 adjusts the predicted data rate from the rate predicted by FIG. 8 according to the quality rating of the gauge mix.

FIG. 9 is a flow chart illustrating a method 110 of finding a line model for any selected customer line 12-14, 19, 21, i.e. either connected or unconnected to the switch 15 of FIG. 1. First, the computer 24 determines whether the selected line is connected to the switch 15 (step 112). If the selected line is connected, the computer 24 chooses the selected line itself for one-ended electrical measurements (step 114). If the selected line is unconnected, e.g., the lines 19, 21 of FIG. 1, the computer 24 chooses a proxy line in the same cable 23 for the one-ended electrical measurements (step 116). Next, the computer 24 and measurement unit 22 perform the one-ended measurements of the chosen line's admittances Y_{tg}, Y_{tr}, Y_{rg} and noise levels as described above (step 118). Next, the computer 245 determines the above-described derived properties for the chosen line from the measured admittances and noise levels as described above (step 120). The derived properties include the frequency dependent attenuation, the absence or existence of a bridged tap, the mix, the frequency-dependent normalized line length, and the averaged normalized line length. From the derived properties, the computer 24 determines the averaged normalized line length using the formula described below (step 122). Similarly, from the measured noise levels of the chosen line, the computer 24 determines the chosen line's normalized noise level. The computer 24 stores the one-ended measurements, the derived electrical properties (step 120), normalized noise level (step 124), and averaged normalized line length (step 122) as the line model for the originally selected

line 12-14, 19, 21 (step 126). These stored quantities form a footprint that characterizes the customer line.

The footprint is stored data on the condition of the line when operating well. Later, the computer 24 can call up the footprint to perform speed path testing. When called up, the footprint is useful for fault detection as described in U.S. Patent 5,699,402, which is herein incorporated by reference in its entirety.

The derived properties characterizing the selected customer line 12-14 and modem models used by the methods of FIGs. 4A-4D are found through methods referred to as "data mining". Data mining produces derived properties that are well correlated with the data produced by the models, e.g., high frequency attenuation.

FIG. 10 illustrates a method 130 for using data mining to find derived properties correlating well with the high frequency attenuation. Data mining starts by selecting a sample line having a known attenuation from a sample pool (step 132). Next, one-ended measurements are performed on the selected sample line and a selected set of derived properties, e.g., low frequency admittances, are found from the measurements (step 134). Next, the values of the selected derived properties are stored in a file indexed by the attenuation of the sample line (step 136). Next, the data mining system determines whether other sample lines remain (step 138). If sample lines remain, the system repeats steps 132, 134, 136, and 138. Otherwise, the system compares the values of the derived properties for the sample lines to determine which properties or sets of properties correlate well with the attenuation (step 140). Finally, the system uses the

values of the derived properties correlating well to formulate a set of rules, which determine the attenuation in terms of the well-correlating derived properties (step 142). The "rules" are represented by the methods of FIGs. 4A-4D.

FIG. 11 is a flow chart illustrating a method of marketing customer lines for data transmission. First, the computer 24 of FIG. 1 speed pre-qualifies a plurality of the lines 12-14, 19, 21 using one-ended electrical measurements and speed qualification methods described above (step 152). The speed pre-qualification, at least, classifies each line for either high-speed service or low speed service. Next, the TELCO offers high-speed service to a portion of the customers who have lines qualified for the high-speed service (step 154). Next, the TELCO selectively connects at least a portion of the lines qualified for high-speed service to customers requesting the high-speed service (step 156). The TELCO also sets billing rates for, at least, a portion of the lines at prices that depend on the speed qualification (step 158).

Other embodiments are within the scope of the following claims.

What is claimed is: